



Standard Test Method for Evaluation of Automotive Engine Oils for Valve-Train Wear Performance in Cummins ISB Medium-Duty Diesel Engine¹

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INTRODUCTION

Any properly equipped laboratory, without outside assistance, can use the procedure described in this test method. However, the ASTM Test Monitoring Center (TMC)² provides reference oils and an assessment of the test results obtained on those oils by the laboratory. By these means, the laboratory will know whether its use of the test method gives results statistically similar to those obtained by other laboratories. Furthermore, various agencies require that a laboratory utilize the TMC services in seeking qualification of oils against specifications. For example, the U.S. Army imposes such a requirement in connection with several Army engine lubricating oil specifications.

Accordingly, this test method is written for use by laboratories that utilize the TMC services. Laboratories that choose not to use these services may simply ignore those portions of the test method that refer to the TMC.

This test method may be modified by means of information letters issued by the TMC.² In addition, the TMC may issue supplementary memoranda related to the method.

1. Scope

1.1 This test method, commonly referred to as the Cummins ISB Test, covers the utilization of a modern, 5.9-L, diesel engine equipped with exhaust gas recirculation and is used to evaluate oil performance with regard to valve-train wear.

1.2 The values stated in either SI units, inch-pound units, or other units are to be regarded separately as the primary units.

1.2.1 For each parameter, the primary units are shown first. Secondary units may be shown in parentheses, for information purposes only. These secondary units may or may not be exact equivalents to the primary units.

1.2.2 SI units are provided for all parameters except where there is no direct equivalent such as the units for screw threads, national pipe threads/diameters, and tubing size.

1.2.3 See also [A8.1](#) for clarification; it does not supersede [1.2.1](#) and [1.2.2](#).

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See [Annex A1](#) for general safety precautions.

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² ASTM Test Monitoring Center, 6555 Penn Avenue, Pittsburgh, PA 15206-4489. www.astmtmc.cmu.edu.

2. Referenced Documents

2.1 ASTM Standards:³

- D86** Test Method for Distillation of Petroleum Products at Atmospheric Pressure
- D93** Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
- D97** Test Method for Pour Point of Petroleum Products
- D130** Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test
- D235** Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent)
- D445** Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
- D482** Test Method for Ash from Petroleum Products
- D524** Test Method for Ramsbottom Carbon Residue of Petroleum Products
- D613** Test Method for Cetane Number of Diesel Fuel Oil
- D664** Test Method for Acid Number of Petroleum Products by Potentiometric Titration
- D976** Test Method for Calculated Cetane Index of Distillate Fuels
- D1319** Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
- D2274** Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)
- D2500** Test Method for Cloud Point of Petroleum Products
- D2622** Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry
- D2709** Test Method for Water and Sediment in Middle Distillate Fuels by Centrifuge
- D3338** Test Method for Estimation of Net Heat of Combustion of Aviation Fuels
- D4052** Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
- D4175** Terminology Relating to Petroleum, Petroleum Products, and Lubricants
- D4294** Test Method for Sulfur in Petroleum and Petroleum Products by Energy Dispersive X-ray Fluorescence Spectrometry
- D4739** Test Method for Base Number Determination by Potentiometric Hydrochloric Acid Titration
- D5185** Test Method for Determination of Additive Elements, Wear Metals, and Contaminants in Used Lubricating Oils and Determination of Selected Elements in Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)
- D5186** Test Method for Determination of the Aromatic Content and Polynuclear Aromatic Content of Diesel Fuels and Aviation Turbine Fuels By Supercritical Fluid Chromatography
- D5453** Test Method for Determination of Total Sulfur in Light Hydrocarbons, Spark Ignition Engine Fuel, Diesel

- Engine Fuel, and Engine Oil by Ultraviolet Fluorescence
- D5967** Test Method for Evaluation of Diesel Engine Oils in T-8 Diesel Engine
- D6078** Test Method for Evaluating Lubricity of Diesel Fuels by the Scuffing Load Ball-on-Cylinder Lubricity Evaluator (SLBOCLE)
- D6838** Test Method for Cummins M11 High Soot Test
- D6975** Test Method for Cummins M11 EGR Test
- E29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E178** Practice for Dealing With Outlying Observations
- E344** Terminology Relating to Thermometry and Hydrometry

3. Terminology

3.1 Definitions:

3.1.1 *blind reference oil, n*—a reference oil, the identity of which is unknown by the test facility.

3.1.1.1 *Discussion*—This is a coded reference oil that is submitted by a source independent from the test facility. **D4175**

3.1.2 *blowby, n*—in internal combustion engines, the combustion products and unburned air-and-fuel mixture that enter the crankcase. **D4175**

3.1.3 *calibrate, v*—to determine the indication or output of a measuring device with respect to that of a standard. **E344**

3.1.4 *candidate oil, n*—an oil that is intended to have the performance characteristics necessary to satisfy a specification and is to be tested against that specification. **D4175**

3.1.5 *crosshead, n*—an overhead component, located between the rocker arm and each intake-valve and exhaust-valve pair, that transfers rocker arm travel to the opening and closing of each valve pair.

3.1.5.1 *Discussion*—Each cylinder has two crossheads, one for each pair of intake valves and exhaust valves. **D6838**

3.1.6 *exhaust gas recirculation (EGR), n*—a method by which a portion of engine's exhaust is returned to its combustion chambers via its inlet system. **D6975**

3.1.7 *heavy-duty, adj*—in internal combustion engine operation, characterized by average speeds, power output and internal temperatures that are close to the potential maximums. **D4175**

3.1.8 *non-reference oil, n*—any oil other than a reference oil, such as a research formulation, commercial oil or candidate oil. **D4175**

3.1.9 *non-standard test, n*—a test that is not conducted in conformance with the requirements in the standard test method; such as running in an uncalibrated test stand or using different test equipment, applying different equipment assembly procedures, or using modified operating conditions. **D4175**

3.1.10 *overhead, n*—in internal combustion engines, the components of the valve-train located in or above the cylinder head. **D6838**

3.1.11 *reference oil, n*—an oil of known performance characteristics, used as a basis for comparison.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.11.1 *Discussion*—Reference oils are used to calibrate testing facilities, to compare the performance of other oils, or to evaluate other materials (such as seals) that interact with oils. **D4175**

3.1.12 *sludge, n—in internal combustion engines*, a deposit, principally composed of insoluble resins and oxidation products from fuel combustion and the lubricant, that does not drain from engine parts but can be removed by wiping with a cloth. **D4175**

3.1.13 *test oil, n*—any oil subjected to evaluation in an established procedure. **D4175**

3.1.14 *valve-train, n—in internal combustion engines*, the series of components such as valves, crossheads, rocker arms, push rods and camshaft, that open and close the intake and exhaust valves. **D6838**

3.1.15 *wear, n*—the loss of material from a surface, generally occurring between two surfaces in relative motion, and resulting from mechanical or chemical action or a combination of both.⁴

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *lug, v—in internal combustion engine operation*, to run the engine in a condition characterized by a combined mode of relatively low-speed and high-power output, with the potential to cause hesitation.

3.2.2 *ramp, v*—to change an engine condition at a prescribed rate when changing from one set of operating conditions to another set of operating conditions.

3.2.2.1 *Discussion*—When ramping the engine speed down to a condition such that the engine lugs, the speed is forced down by increasing the load in a such a way that the speed comes to idle before zero load condition is reached.

3.2.3 *tappet, n—in internal combustion engines*, a valve-train component, located between the camshaft and push rod, that transfers cam lobe travel to the rocker arm, opening and closing a pair of intake or exhaust valves.

4. Summary of Test Method

4.1 This test method uses a Cummins 5.9-L, ISB diesel engine equipped with exhaust gas recirculation and featuring an EPA 2004 emissions configuration. Test operation includes a 17-min warm-up, an 80-h break-in and a 350-h test cycle comprising stages A and B. During stage A the engine is operated with retarded, fuel-injection timing to generate excess soot; during stage B the engine is operated at cyclic conditions to induce valve-train wear.

4.2 Prior to each test, the engine is cleaned and assembled with new, valve-train components. All aspects of the assembly are specified.

4.3 A forced oil drain, an oil sampling, and an oil addition are performed at the end of each 25-h period for the first 100 h of the test. Thereafter, oil samples are taken every 50 h. Oil additions are not made during the last 250 h of the test cycle.

4.4 The test stand is equipped with the appropriate instrumentation to control engine speed, fuel flow and other operating parameters.

⁴ *Glossary of Terms and their Definitions*, Published by ASTM Test Monitoring Center and available under *Subcommittee B Glossary* section on the TMC website, www.astmtmc.cmu.edu.

4.5 Oil performance is determined by assessing crosshead wear, tappet weight loss and camshaft wear.

5. Significance and Use

5.1 This test method was developed to assess the performance of a heavy-duty engine oil in controlling engine wear under operating conditions selected to accelerate soot production and valve-train wear in a turbocharged and aftercooled four-cycle diesel engine with sliding tappet followers equipped with exhaust gas recirculation hardware.

5.2 The design of the engine used in this test method is representative of many, but not all, modern diesel engines. This factor, along with the accelerated operating conditions, shall be considered when extrapolating test results.

6. Apparatus

6.1 Test-Engine Configuration:

6.1.1 *Test Engine*—The Cummins ISB is a 5.9-L, in-line, six-cylinder, diesel engine. It is turbocharged, aftercooled, and has an overhead valve configuration. It features a 2004 emissions configuration with electronic control of fuel metering and common rail fuel injection. Obtain the test engine and the engine build parts kit from the Central Parts Distributor (CPD).^{5,6} The components of the engine build parts kit are shown in **Table A3.1**.

6.1.2 *Remote Oil Heat Exchanger and Bypass Plate*—Remove the stock oil heat exchanger from the engine and replace with a bypass plate (part number ISB-OCBP)^{5,6} shown in **Fig. A4.1**. Attach a remote bypass (part number 149-0118-00)^{6,7} to the filter head, as shown in **Fig. A4.2**. The bypass allows control of the oil temperature by directing the oil to flow through a 76 mm × 102 mm (3 in. × 14 in.) dual-pass, remote oil heat exchanger (part number SN16-003-014-004)^{6,8} as shown in **Fig. A4.3**. The oil lines to and from the remote oil heat exchanger and filter head shall not be greater than one 1 m long and shall be 19.3 mm (% in.) nominal outer diameter tubing (Aeroquip⁹ “-12” or equivalent).

6.1.3 *Oil Pan Modification*—Modify the oil pan as shown in **Fig. A4.4**.

6.1.4 *Engine Control Module (ECM)*—Obtain the ECM from the CPD.^{5,6} Information about the ECM is given in a Cummins publication.^{10,11} Use the latest Cummins engineering tools¹¹ to retard injection timing in order to increase soot

⁵ This CPD is the sole source of supply of the test engine, engine build parts kit and the ECM known to the committee at this time is Test Engineering, Inc., 12718 Cimarron Path, Suite 102, San Antonio, TX 78249-3423, www.tei-net.com.

⁶ If you are aware of alternative suppliers, please provide this information to ASTM. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

⁷ The sole source of supply of this bypass known to the committee at this time is W G Sourcing, Inc., 2650 Pleasantdale Road #10, Atlanta, GA 30340. www.wg-sourcing.net.

⁸ The sole source of supply of the remote oil heat exchanger known to the committee at this time is Kinetic Engineering Corporation, 2055 Silber Road, Suite 101, Houston, TX 77055. www.kineticengineering.com.

⁹ Aeroquip lines are available at a local hose distributors.

¹⁰ *Troubleshooting and Repair Manual ISB, ISB*, QSB 4.5, QSB 5.9, QSB 6.7, ISC, QSC 8.3, ISL and QSL 9 Engines, CM 850 Electronic Control System Engines*, Bulletin Number 4021416.

¹¹ Available from local Cummins parts distributors.

TABLE 1 Maximum Allowable System Time Responses

Measurement Type	Time Response, s
Speed	2.0
Load	2.0
Temperature	3.0
Pressure	3.0
Flow	45.0

generation and overhead wear. Verify that the 2004 EPA calibration is used. Some engine protection protocols have been disabled to ensure that the test is run according to the procedure. Obtain prior authorization and instructions from Cummins Inc.¹² on how to disable the engine protection protocols and the use of Cummins engineering tools.

6.1.5 *Air Compressor*—The engine-mounted air compressor is not used for this test method. Remove the air compressor and cover the opening by a plate (part number 3954567).¹¹

6.1.6 *Engine Inlet Air Heater*—Remove the internal heating elements from the housing of the engine inlet air heater. Remove the lower, factory-installed, electrical terminal. Drill and tap this hole (1/8 in. NPT) for the inlet manifold pressure fitting.

6.2 Test-Stand Configuration:

6.2.1 *Engine Mounting*—Install the engine so that it is upright and the crankshaft is horizontal, with minimal block distortion. Due to the cyclic nature of the test, a driveline coupling damper is required.¹³

6.2.2 *Intake Air System*—the configuration is shown in Fig. A4.6. Use a cobra elbow (part number 3037625).^{5,11} Connect to the cobra elbow using straight, 100-mm (4-in.) diameter tubing with a minimum length of 300 mm (12 in.). Use an air filter typical of those used in diesel engine testing applications. Install the intake air tube (Fig. A4.6) at the intake of the turbocharger compressor. Construct the system to minimize airflow restriction. Install methods for controlling the intake air temperature and pressure.

NOTE 1—Difficulty in achieving or maintaining intake manifold pressure or intake manifold temperature, or both, could be indicative of insufficient or excessive restriction.

6.2.3 *Aftercooler*—Use a Modine aftercooler for aftercooling. Instructions for obtaining the correct aftercooler are listed in A2.1. An installation photograph is shown in Fig. A4.10.

6.2.4 *Exhaust System*—Install a long-radius, 90°-elbow, exhaust tube (see Fig. A4.11) at the discharge flange of the turbocharger housing, followed by a sufficient length of straight tubing to allow the temperature and pressure sensors to be located 152 mm (6.0 in.) downstream of the elbow weld seam. Use good engineering practice in establishing the total length and diameter of the tube downstream of the sensors. Install a method of controlling exhaust back pressure.

6.2.5 *Exhaust Gas Recirculation System*—The components for the exhaust gas recirculation system are installed by the manufacturer. Replacement parts are available.^{5,11}

6.2.6 *Fuel Supply*—The laboratory fuel supply and filtration systems are not specified. Determine the fuel-consumption rate by measuring the rate of fuel flowing into the day tank. Install a method of controlling the fuel temperature. Ensure the fuel-inlet restriction and return restrictions adhere to the requirements specified in the Cummins Service Manual.^{11,14}

6.2.7 *Coolant System*—The coolant system configuration is not specified. A typical configuration consists of a non-ferrous-core heat exchanger, a reservoir (expansion tank), and a temperature-control valve. Pressurize the system by regulating air pressure at the top of the expansion tank. Install a sight glass to detect air entrapment.

NOTE 2—**Caution:** Although the system volume is not specified, an excessively large volume can increase the time required for the engine fluid temperatures to attain specification. A system volume of 35 L or less (including engine) has been found satisfactory.

6.2.7.1 Block the engine thermostat wide open.

6.2.8 *Pressurized Oil-Fill System*—The oil-fill system is not specified. A typical configuration includes an electric pump, a 20-L reservoir and transfer hose.

6.2.9 *External Oil System*—Configure the external oil system according to Fig. A5.1, using an external reservoir with a volume between 4 L and 8 L. Use Viking Pump (model number SG041825)¹⁵ for the external pumps with a nominal pump-motor speed of 1140 r/min. A three-way valve system is permissible and allows the reservoir to be emptied back into the oil pan at the start of Stage B. The location of the three-way valve is not specified (location shown in Fig. A5.1 is for example only).

6.2.9.1 *Oil-Sample Valve Location*—Locate the oil-sample valve on the return line from the remote oil heat exchanger system to the engine. It is recommended that the valve be located as shown in Fig. A4.9.

6.2.9.2 Do not use brass or copper fittings in the external oil system because such metals can influence wear-metals analyses of the used oil.

6.2.10 *Crankcase Aspiration*—Vent the blowby gas at the port located at the left rear of the flywheel housing, as shown in Fig. A4.5. Ensure the vent line proceeds in a downward direction into the collection bucket and that the collection bucket has a minimum volume of 19 L (5 gal).

6.2.11 *Blowby Rate*—The flow-rate device and system configuration are not specified. Install the system according to good engineering practice and operate the flow-rate device according to the manufacturer's guidelines.

6.3 *System Time Responses*—Table 1 shows the maximum allowable system time responses. Determine system time responses in accordance with the Data Acquisition and Control Automation II (DACA II) Task Force Report.¹⁶

6.4 *Oil-Sample Containers*—High-density polyethylene containers are recommended for oil samples. (**Warning**—

¹⁴ *Troubleshooting and Repair Manual for ISB® and ISB (Common Rail Fuel System) Series Engines*, Bulletin Number 4021271, June 30, 2004, published by Cummins Inc.

¹⁵ The sole source of supply of the apparatus known to the committee at this time is Viking Pump, Inc., (unit of IDEX Corporation), 406 State St., P.O. Box 8, Cedar Falls, IA 50613-0008. www.vikingpumps.com.

¹⁶ Available from the TMC website: www.astmtmc.emu.edu.

¹² Cummins Inc., 1900 McKinley Avenue, Columbus, IN 47201.

¹³ The sole source of supply of the apparatus known to the committee at this time is Vulkan Driveline Coupling (Part Number VKL3415, available from American Vulkan USA, 2525 Dundee Road, Winter Haven, FL 33484. www.vulkanusa.com.

Glass containers may break and may cause injury or exposure to hazardous materials, or both.)

6.5 *Mass Balance*—Use a balance (electronic or mechanical) with a minimum indication resolution of 0.1 mg to measure the mass of the crossheads and tappets.

7. Engine Fluids and Cleaning Solvents

7.1 *Test Oil*—Approximately 80 L of test oil are required to complete the test.

7.2 *Test Fuel*—Approximately 8000 L of PC-10 (ultra-low-sulfur) diesel fuel^{6,17} are required to complete the test. The fuel shall have the properties and tolerances shown in **Annex A6**.

7.3 *Engine Coolant*—Use 50:50 pre-mixed Fleetguard Compleat PG.¹¹

7.4 *Solvents and Cleaners Required*—(**Warning**—Use adequate safety precautions with all solvents and cleaners.)

7.4.1 *Solvent*—Use mineral spirits meeting Specification **D235**, Type II, Class C requirements for aromatic content (0 to 2 % vol), flash point (61°C), and color (not darker than +25 on Saybolt Scale or 25 on Pt-Co Scale). Obtain a Certificate of Analysis for each batch of solvent from the supplier. (**Warning**—Combustible. Health hazard.)

7.4.2 *Pentane*—Used for rinsing and cleaning components before measurement. (**Warning**—Flammable. Health hazard.)

7.4.3 *Degreasing Solvent*—EnSolv,¹⁸ a proprietary *n*-propyl bromide based solvent used for cleaning the tappets. (**Warning**—Health hazard.)

8. Preparation of Apparatus

8.1 *Cleaning of Parts*:

8.1.1 *General*—This section describes the preparation of test engine components specific to the Cummins ISB test. Use the Cummins service publications listed in **Annex A7** for the preparation of other engine components. Take precautions to prevent rusting of iron components. Additionally, perform any engraving of test parts for identification purposes on non-contact surfaces and follow by the pre-test cleaning as specified in the following sections.

8.1.2 *Engine Block*—The engine block is a parent bore type. This test does not require a complete teardown. Do not clean the internal surfaces and passages of the engine block with solvent.

8.1.3 *Rocker Cover and Oil Pan*—Clean the rocker cover and oil pan with solvent (see **Warning** in 7.4.1). Use a brush as necessary to remove deposits.

8.1.4 *External Oil System*—Flush the internal surfaces of the oil lines and the external reservoir with solvent. Repeat until the solvent drains clean. Flush solvent through the oil pumps until the solvent drains clean.

8.1.5 *Crosshead Cleaning and Measurement*—Do not handle the crossheads with bare hands; use gloves or plastic-covered tongs.

¹⁷ The sole source of supply of the PC-10 test fuel known to the committee at this time is Chevron Phillips Chemical Company LP, 10001 Six Pines Drive, Suite 4036B, The Woodlands, TX 77387-4910. www.cpchem.com.

¹⁸ EnSolv is a registered trademark of, and is available from, Enviro Tech International, Inc., 2525 West LeMoyné Ave., Melrose Park, IL 60160. www.ensolv.com.

8.1.5.1 Clean the crossheads with solvent. Use a non-metallic, soft-bristle brush if necessary.

8.1.5.2 Allow the crossheads to air dry (do not use compressed air).

8.1.5.3 Rinse the crossheads in pentane (see **Warning** in 7.4.2) and allow to air dry (do not use compressed air).

8.1.5.4 Measure each crosshead mass to a tenth of a milligram (xxx.x mg).

8.1.5.5 If an electronic scale is used for mass measurement, use the following procedure:

(1) Demagnetize (degauss) each crosshead prior to measurement.

(2) Measure each crosshead mass twice, using two orientations 90° apart. If the difference between the two mass measurements is greater than 0.2 mg, demagnetize the crosshead again and repeat the measurement process.

8.1.5.6 For laboratories using the TMC services, report the crosshead measurements on the form included in the TMC report package (see 12.1).

8.1.6 *Tappet Cleaning and Measurement*—Do not handle the tappets with bare hands; use EnSolv-compatible gloves or plastic covered tongs.

8.1.6.1 Inspect the tappets for damage and clean with solvent. Use a non-metallic, soft-bristle brush if necessary.

8.1.6.2 Allow the tappets to air dry (do not use compressed air).

8.1.6.3 Rinse the tappets with pentane and allow to air dry (do not use compressed air).

8.1.6.4 Soak the tappets in EnSolv (see **Warning** in 7.4.3) for 30 min, ensuring that each tappet is completely immersed in the solvent.

8.1.6.5 Allow the tappets to air dry (do not use compressed air).

8.1.6.6 Measure the mass of each tappet, orienting the large, circular, flat surface in an upwards position, to a tenth of a milligram (xxx.x mg).

8.1.6.7 If an electronic scale is used for mass measurement, use the following procedure:

(1) Demagnetize (degauss) each tappet prior to measurement.

(2) Measure the tappet twice, using two orientations, both with the flat face upwards, 90° apart. If the difference between the two mass measurements is greater than 0.2 mg, demagnetize the tappet again and repeat the measurement process.

8.1.6.8 For laboratories using the TMC services, report the tappet measurements on the forms included in the TMC report package (see 12.1).

8.1.7 *Camshaft Cleaning and Measurement*—Clean the camshaft with solvent. Because contamination can adversely affect the wear results, use gloves, not bare hands, to handle the camshaft.

8.1.7.1 Measure the cam lobe heights (heel-to-toe) using a Mitutoyo Snap Gauge (model 201-152),¹⁹ and a Mitutoyo Digital Indicator (model 543-252B).¹⁹

¹⁹ The sole source of supply of the apparatus known to the committee at this time is Mitutoyo America Corporation, 965 Corporate Blvd., Aurora, IL 60502. www.mitutoyo.com.

8.1.7.2 Measure three locations on each lobe: the front edge, the center, and the rear edge. Report the lobe measurement as the average of the three values.

8.1.7.3 For laboratories using the TMC services, report the lobe measurements on the forms included in the TMC report package (see 12.1).

8.2 Engine Assembly:

8.2.1 *General*—Except as noted in this section, use the procedures indicated in the Cummins service publications (see Annex A7). Assemble the engine with the components from the ISB Engine Build Parts Kit in numerical order, from front to rear (see Annex A3 for details of the kit).

8.2.2 *Parts Reuse and Replacement*—Except as directed in 8.2.5, engine components may be reused or replaced at the discretion of the laboratory (Cummins Critical Parts List, CPL #8123). The engine block may be reused provided that it meets the serviceability requirements, particularly blowby and cam bore, defined in the Cummins Service Manual.¹¹

8.2.3 *Build-Up Oil*—Use the Cummins-branded oil meeting Cummins Engineering Standard 20078.¹¹

8.2.4 *Coolant Thermostat*—Lock the engine coolant thermostat open to close off the bypass passage in the engine block.

8.2.5 *New Parts*—The parts listed below are contained in the ISB Engine Build Parts Kit and are not reusable. Prior to use, clean the valve-train parts with solvent. With the exception of the fuel filter, replacement of any part listed below during a test invalidates the test.

8.2.5.1 *Rocker Lever Shafts.*

8.2.5.2 *Rocker Lever Assemblies, Complete with Sockets.*

8.2.5.3 *Tappets.*

8.2.5.4 *Rocker Lever Sockets.*

8.2.5.5 *Push Rods.*

8.2.5.6 *Valve Crossheads.*

8.2.5.7 *Camshaft.*

8.2.5.8 *Test Oil Filter.*

8.2.5.9 *Fuel Filter*—Replacement during a test does not invalidate the test.

8.2.6 The entire engine may be replaced during a reference period provided the engine completes the 80-h, new-engine, break-in cycle specified in 10.1.

8.2.7 Do not replace the cylinder head and power cylinder components during the life of the engine.

8.3 Operational Measurements:

8.3.1 *Units and Formats*—See Annex A8. Record operational parameters in accordance with the minimum resolutions given in Table A8.1.

8.3.2 Instrumentation Calibration:

8.3.2.1 *Calibration of the Fuel Consumption Rate Measurement System*—Calibrate the fuel consumption rate measurement system before every reference oil test sequence and within nine months after the completion of the last successful calibration test. Volumetric systems shall be temperature-compensated and calibrated against a mass flow device. The flow meter located on the test stand shall indicate within 0.2 %

of the calibration standard. The calibration standard shall be traceable to the National Institute for Standards and Technology (NIST).²⁰

8.3.2.2 *Calibration of the Temperature Measurement Systems*—Calibrate the temperature measurement systems before every reference oil test sequence and within nine months after the completion of the last successful calibration test. Each temperature measurement system shall indicate within $\pm 0.5^\circ\text{C}$ of the laboratory calibration standard. The calibration standard shall be traceable to NIST.²⁰

8.3.2.3 *Calibration of the Pressure Measurement Systems*—Calibrate the pressure measurement systems before every reference oil test sequence and within nine months after the completion of the last successful calibration test. The calibration standard shall be traceable to NIST.²⁰

8.3.3 Temperature Measurements:

8.3.3.1 *Measurement Location*—This section specifies the temperature measurement locations. The measurement equipment is not specified. Install the sensors such that the tip is located midstream of the flow unless otherwise indicated. Follow the guidelines detailed in the DACA II Task Force Report¹⁶ for the accuracy and resolution of the temperature measurement sensors and the complete measurement system.

8.3.3.2 *Coolant-Out Temperature*—Install the sensor as shown in Fig. A4.15(a).

8.3.3.3 *Coolant-In Temperature*—Install the sensor on the right side of the engine on the inlet pipe to the coolant pump intake housing, as shown in Fig. A4.15(b).

8.3.3.4 *Fuel-In Temperature*—Install the sensor in the fuel pump inlet fitting, as shown in Fig. A4.13. The maximum allowable sensor size is 4.8 mm ($3/16$ in.) diameter. Install the sensor to the center of the banjo fitting.

8.3.3.5 *Oil Gallery Temperature*—Install the sensor at the metric, straight-thread hole on the left front of the engine, near the ECM, as shown in Fig. A4.12.

8.3.3.6 *Intake Air Temperature*—Install the sensor as shown on Fig. A4.6. Locate the sensor 150 mm to 200 mm (6 in. to 8 in.) upstream of the cobra elbow; ensure that there is at least 150 mm (6 in.) of straight tubing upstream of the sensor. Do not install the sensor upstream of the intake air pressure tap.

8.3.3.7 *Intake Manifold Temperature*—Install the sensor at the top of the aluminum snorkel on the air inlet tube, as shown in Fig. A4.7. The insertion depth shall be 114 mm (4.5 in.) from the outside surface of the aluminum snorkel.

8.3.3.8 *Exhaust Temperature*—Install the sensor as shown in Fig. A4.11.

8.3.3.9 *Oil Sump Temperature*—Install the sensor at an insertion depth of 60 mm (2.4 in.) from the outside pan boss identified as the Factory/OEM metric-threaded hole, as shown in Fig. A4.4(a).

8.3.3.10 *Additional Temperature Measurements*—Monitor any additional temperatures that the laboratory considers beneficial.

NOTE 3—Measurement of the EGR cooler gas inlet and outlet, and coolant inlet and outlet temperatures is recommended. Additional exhaust temperature sensor locations, such as the exhaust ports and pre-turbine

²⁰ National Institute for Standards and Technology, www.nist.gov.

(front and rear), are also recommended. The detection of changes in exhaust temperature(s) is an important diagnostic in terms of satisfactory engine operation.

8.3.4 Pressure Measurements:

8.3.4.1 Measurement Location and Equipment—This section specifies the pressure measurement locations. The measurement equipment is not specified. Follow the guidelines detailed in the DACA II Task Force Report¹⁶ for the accuracy and resolution of the pressure measurement sensors and the complete measurement system.

NOTE 4—It is beneficial to install a condensation trap at the lowest elevation of the tubing between the pressure measurement location and the final pressure sensor for crankcase pressure, intake air pressure, and exhaust pressure. Route the tubing to avoid intermediate loops or low spots before and after the condensation trap.

8.3.4.2 Oil Gallery Pressure—Measure the pressure at the metric, straight-thread fitting on the left front of the engine, located near the ECM, as shown in **Fig. A4.12**.

8.3.4.3 Oil Filter Inlet Pressure—Measure the pressure at the 1/8 in. NPT port located on the remote oil filter assembly, as shown in **Fig. A4.9**.

8.3.4.4 Oil Filter Outlet Pressure—Measure the pressure at the 1/8 in. NPT port located on the remote oil filter assembly, as shown in **Fig. A4.9**.

8.3.4.5 Intake Manifold Pressure—Measure the pressure at the 1/4 in. NPT port located in the air heater block at the top-front of the intake manifold, as shown in **Fig. A4.8**.

8.3.4.6 Crankcase Pressure—Measure the pressure at the dipstick port located on the left side of the test engine, as shown in **Fig. A4.12**.

8.3.4.7 Intake Air Pressure—Measure the pressure on the intake air tube, as shown in **Fig. A4.6**. Locate the pressure tap 150 mm to 200 mm (6 in. to 8 in.) upstream of the cobra elbow; ensure that there is at least 150 mm (6 in.) of straight tubing upstream of the sensor.

8.3.4.8 Exhaust Back Pressure—Measure the static pressure through a hole in the exhaust tube, as shown in **Fig. A4.11**.

8.3.4.9 Fuel Pressure—Measure the pressure on the engine-mounted outlet of the fuel filter, as shown in **Fig. A4.14**.

8.3.4.10 Coolant Pressure—Measure the pressure on top of the expansion tank.

8.3.4.11 Additional Pressure Measurements—Monitor any additional pressures considered to be beneficial.

8.3.5 Flow Rate:

8.3.5.1 Flow-Rate Location and Measurement Equipment—The flow-rate measurement locations are specified in this section. The equipment or type of system for the blowby and fuel flow rates is not specified. Follow the guidelines detailed in the DACA II Task Force Report¹⁶ for the accuracy and resolution of the flow-rate measurement system.

8.3.5.2 Blowby Flow Rate—Use engineering judgment and the manufacturer's guidelines concerning the installation and use of the blowby flow-rate measurement device.

8.3.5.3 Fuel Flow Rate—Determine the fuel consumption rate by measuring the fuel flowing to the day tank.

9. Engine/Stand Calibration and Non-Reference Oil Tests

NOTE 5—This section is addressed to those laboratories that choose to utilize the services of the TMC² in maintaining calibration of the test stand.

9.1 General—Calibrate the test engine and the test stand by conducting a test with a blind reference oil.² Submit the results to the TMC² for determination of acceptance according to the Lubricant Test Monitoring System (LTMS).

9.1.1 Because the Cummins ISB common rail engine is a parent bore block and is not completely rebuilt before each test, an engine is not referenced to a stand. The stand is calibrated for use with different ISB common rail engines as supplied from the CPD.⁵

9.2 New Test Laboratory/Stand—A new test laboratory is defined as a laboratory that has never successfully calibrated a test stand. The first test stand at a new laboratory requires two successful calibration tests to establish its first calibration period. All subsequent calibration periods on that stand or any other stand within that laboratory require one successful calibration test.

9.3 Stand Calibration Period:

9.3.1 The first two calibration periods on a new test stand are carried out 12 months or 12 operationally valid non-reference oil tests, whichever comes first, from the completion of the last successful calibration test.

9.3.2 All subsequent calibration periods on a test stand are 18 months or 12 operationally valid non-reference oil tests, whichever comes first, from the completion of the last successful calibration test.

9.3.3 Last Start Date—A non-reference oil test may be completed provided the warm-up is started prior to the expiration of the calibration period.

9.4 Stand Modification and Calibration Status—Modification of the test stand control systems or the conducting of any non-standard test, or both, can invalidate the calibration status. A non-standard test includes any test conducted under a modified procedure, non-procedural hardware, controller set-point modifications, or a combination thereof. Contact the TMC² to determine if any such proposed modifications will affect the calibration status.

9.5 Test Numbering System:

9.5.1 General—The test number has four parts, W-X-Y-Z: W represents the test stand number, X represents the run number for that stand (and has a XXX format), Y represents the eight-digit serial number for that engine, and Z represents the number of test hours completed by that engine block prior to starting the test and has a format XXXX. The value for the number of test hours on the engine, Z, does NOT include the 80-h break-in time (see **10.1**) nor does it include time for warm-up and cool-down run times. As an example, test number 64-002-57216596-0350 indicates stand number 64, test number 002 for that stand, engine serial number 57216596, and the engine has 0350 test h prior to starting this test on engine block 57216596. Every test start (reference oil and non-reference oil) increments X by one.

9.5.2 *Reference Oil Tests*—The sequential stand run number remains unchanged for reruns of aborted, invalid, or unacceptable calibration tests. However, follow the sequential stand run number by a letter suffix (A for the first rerun, B for the second, and so forth).

9.5.3 *Non-Reference Oil Tests*—Do not add a letter suffix to X for aborted or operationally invalid, non-reference oil tests.

9.6 *Reference Oil Test Acceptance:*

9.6.1 Reference oil test acceptance is determined in accordance with the LTMS.²

9.7 *Reference Oil Accountability:*

9.7.1 Laboratories shall provide a full accounting of the identification and quantities of all reference oils used. With the exception of the oil analyses required in 11.4, perform no physical or chemical analyses of reference oils without written permission from the TMC. In such an event, include the written confirmation and the data generated in the reference oil test report.

9.7.2 Retain used reference oil samples for 90 days from the End of Test (EOT) date.

9.8 *Donated Reference Oil Test Programs*—The ASTM D02.B0.02 Cummins Surveillance Panel is charged with maintaining effective reference oil test severity and precision monitoring. During times of new parts introductions, new or re-blended reference oil additions, and procedural revisions, it may be necessary to evaluate the possible effects on severity and precision levels. The Surveillance Panel may choose to conduct a program of donated reference oil tests in those laboratories participating in the monitoring system, in order to quantify the effect of a particular change on severity and precision. Typically, the Surveillance Panel requests its panel members to volunteer enough reference oil test results to create a robust data set. Broad laboratory participation is needed to provide a representative sampling of the industry. To ensure the quality of the data obtained, donated tests are conducted on calibrated test stands. The Surveillance Panel shall arrange an appropriate number of donated tests and ensure completion of the test program in a timely manner.

9.9 *Adjustments to Reference Oil Calibration Periods:*

9.9.1 *Procedural Deviations*—On occasions when a laboratory becomes aware of a significant deviation from the test method, such as might arise during an in-house review or a TMC inspection, the laboratory and the TMC shall agree on an appropriate course of action to remedy the deviation. This action may include the shortening of existing reference oil calibration periods.

9.9.2 *Parts and Fuel Shortages*—Under special circumstances, such as industrywide parts or fuel shortages, the Surveillance Panel may direct the TMC to extend the time intervals between reference oil tests. These extensions shall not exceed one regular calibration period.

9.9.3 *Reference Oil Test Data Flow*—To ensure continuous severity and precision monitoring, calibration tests are conducted periodically throughout the year. There may be occasions when laboratories conduct a large portion of calibration tests in a short period of time. This could result in an unacceptably large time frame when very few calibration tests are conducted. The TMC can shorten or extend calibration

periods as needed to provide a consistent flow of reference oil test data. Adjustments to calibration periods are made such that laboratories incur no net loss (or gain) in calibration status.

9.9.4 *Special Use of the Reference Oil Calibration System*—The Surveillance Panel has the option to use the reference oil system to evaluate changes that have potential impact on test severity and precision. This option is only taken when a program of donated tests is not feasible. The Surveillance Panel and the TMC shall develop a detailed plan for the test program. This plan requires all reference oil tests in the program to be completed as close to the same time as possible, so that no laboratory/stand calibration is left in an excessively long pending status. In order to maintain the integrity of the reference oil monitoring system, each reference oil test is conducted so as to be interpretable for stand calibration. To facilitate the required test scheduling, the Surveillance Panel may direct the TMC to lengthen and shorten reference oil calibration periods within laboratories such that the laboratories incur no net loss (or gain) in calibration status.

10. Test Procedure

10.1 *New Engine Break-In*—The engine break-in procedure consists of a sequence of 15-min cycles run for a total of 80 h (see Table 2). With the exception of Step 6 in Table 2, perform changes in load and speed at a rapid rate. This break-in cycle is only required for first-time use engines. The original equipment (OE) oil cooler may be left installed as received; the OE fuel filter and peripherals are also allowed.

10.1.1 *Oil Charge for Break-In*—Install a non-test oil filter (part number LF3970) and pressure charge the engine with 14.5 kg of Cummins branded CES 20078 oil.¹¹ This amount includes oil in the filter.

10.1.2 *Break-In Cycle*—Run the break-in cycle, as detailed in Table 2, for 80 h.

10.1.3 *Post Break-In*—Drain the break-in oil. The engine may now be used for testing and is ready to be equipped and assembled as detailed in sections 6.1 and 8.

10.2 *Pretest Procedure:*

10.2.1 *Pretest Oil Charge*—Install a new, non-test, oil filter (part number LF3970¹¹) and pressure charge the engine with 14.5 kg of test oil. This amount includes oil in the filter.

10.2.2 *Engine Start-up*—For the first start-up with new test parts, start the engine and idle (no load) for no more than 10 s. Within 5 s, ramp the engine to 3000 r/min and no load and hold those conditions for 30 s to break in the cam and tappets.

TABLE 2 15-min Break-in Cycle

Step	Load, N·m	Speed, r/min	Time, s
1	0 % ^A	800	144
2	800 ^B	1600	36
3	800 ^B	2600	360
4	0 % ^A	3000	36
5	800 ^B	2600	144
6	800 ^B	Ramp down from 2600 to 1600	36
7	800 ^{B,C}	1600	108
8	0 % ^A	3000	36

^A No excitation on the dynamometer.

^B Nominal.

^C During step 7, turbocharger surge conditions may occur in the induction system requiring load to be reduced by about 3 to 8 %.

10.2.2.1 Perform this step only once, at the first start-up for new test parts. Do not use it for subsequent start-ups on the same set of test parts.

10.2.2.2 For all subsequent start-ups on the same set of test parts, proceed directly to the 1300 r/min and no load conditions of the engine warm-up as directed in 10.2.3.1.

10.2.3 *Engine Warm-Up Procedure*—Perform all engine start-ups as directed in this section, changing set points in a step-wise fashion.

10.2.3.1 Run the engine at 1300 r/min and no load for 2 min. (If the start-up is for Stage A, start the auxiliary oil pump.)

10.2.3.2 Increase load to 200 N·m for 5 min.

10.2.3.3 Increase load to 400 N·m for 5 min.

10.2.3.4 Increase speed to 2600 r/min and load to 600 N·m for 5 min.

10.2.4 *Pretest Oil Flush*—Operate the engine at 1600 r/min and 440 N·m for 15 min. Shutdown the engine as directed in 10.2.5 and drain the oil for 30 min.

10.2.4.1 Replace the non-test oil filter with another non-test filter. Repeat the pretest oil charge (10.2.1) and the engine warm-up (10.2.3), and operate the 1600 r/min and 440 N·m flush condition for 15 min. Shutdown the engine (10.2.5) and drain the oil for 30 min.

10.2.4.2 Replace the oil filter with a test filter (part number 3937736, which is part of the ISB Engine Build Parts Kit listed in Annex A3).

10.2.5 *Engine Shutdown*—Perform all non-emergency shutdowns as directed in this section, changing set points in a step-wise fashion.

10.2.5.1 *From Stage A Test Condition* (see Table 3):

(1) Decrease engine speed to 1300 r/min and load to 440 N·m for 1 min.

(2) Decrease load to 200 N·m for 1 min.

(3) Run engine at low idle and no load for 2 min.

10.2.5.2 *From Stage B Test Condition* (see Table 3):

(1) Run engine at 1300 r/min and 200 N·m for 2 min.

(2) Run engine at low idle and no load for 2 min.

10.3 *350-h, Two-Stage, Test Cycle*:

10.3.1 *Test-Oil Charge*—Pressure charge the engine with 14.5 kg of test oil. This amount includes oil in the filter.

10.3.2 *Test Conditions*—Warm-up the engine as directed in 10.2.3 and run the 350-h test conditions shown in Tables 3 and 4. At the conclusion of the 350-h test, shutdown the engine as directed in 10.2.5.

10.3.3 *Oil Samples*—Every 25 h from 0 to 100 h, and every 50 h from 150 h to end-of-test, take 120-mL oil samples from the sample valve (see Fig. A4.9). A purge (120 mL for Stage A and 30 mL for Stage B) shall be taken prior to taking the sample. During Stage A, return the purge to the auxiliary oil reservoir; during Stage B, discard the purge. Take oil samples prior to forced additions.

10.3.4 *Stage A Details*:

10.3.4.1 Run at retarded timing (-16° maximum) to generate $3.25 \pm 0.25\%$ soot at 100 h. Use Cummins engineering tool¹¹ to change final timing as indicated on engineering tool display.

10.3.4.2 *Oil Addition/Drain*—Initially establish the full mark as the oil scale weight after 4 h of running Stage A. At 25, 50, 75, and 100 h, drain a sufficient amount of oil to obtain an oil weight that is 1000 g below the full mark. Add back 1000 g of fresh test oil. For any 25-h period in which the oil weight is already more than 1000 g below the full mark, do not perform the force drain.

10.3.4.3 Immediately after the 100 h oil addition, close the auxiliary oil system suction valve, allow the auxiliary oil pumps to empty the external oil reservoir and force the oil into the oil pan. When the external reservoir is empty, close the external oil valves and turn off the external oil pumps. (Perform these actions in the final minutes while the engine is still operating at Stage A conditions.)

10.3.4.4 *Data Collection Minima for Stage A*—Take snapshot readings of all operational data every 6 min.

10.3.5 *Stage B Details*:

10.3.5.1 Table 4 describes the Stage B test cycle. The maximum duration of the cycle is 28 s. Repeat this cycle for 250 h.

10.3.5.2 Return timing to default (native timing) using the Cummins engineering tool.

10.3.5.3 No fresh-oil replacement or additions are allowed throughout Stage B.

10.3.5.4 Stage B length is based on test time. Complete a minimum of 32 000 cycles for the test to be valid. The cycle counter advances at the completion of the last, low-idle step.

10.3.5.5 *Data-Collection Minima for Stage B*—At least every 12 cycles, capture snapshot of all data 1 s before the end of the rated speed stage (5 s into step 2 of Table 4). Every 1000 cycles take a minimum of two consecutive full-cycle traces of speed and load at 10 Hz.

10.4 *Post-Test*:

10.4.1 Drain the test oil for 30 min. Remove the test oil filter.

10.4.2 Install a non-test oil filter. Charge the engine with 14.5 kg of Cummins-branded CES 20078 oil.¹¹ Circulate the oil through the engine for 15 min using an oil flush cart. At the end of 15 min, drain all the flush oil.

10.4.3 Remove, clean, and measure test parts as directed in 8.1.

TABLE 3 Test Conditions

Test Parameter	Stage A	Stage B
Time, h	100	250 ^A
Engine speed, r/min	1600 ± 10	Varies
Load, N·m	Resultant	Varies
Fuel Rate, kg/h	20.0 ± 0.3	Varies
Coolant-out temperature, °C	99 ± 3	99 ± 3 ^B
Coolant pressure, kPa	99 to 107	99 to 107
Intake manifold pressure, kPa	Resultant	Varies
Intake manifold temperature, °C	68 ± 2	68 ± 5 ^B
Inlet-air temperature, °C	25 to 35	25 to 35 ^B
Turbine-inlet temperature, °C	Resultant	Varies
Oil-pan temperature, °C	110 ± 2	110 ± 2 ^B
Oil pressure, kPa	Resultant	Varies
Intake-air restriction, kPa	1 to 3	0 to 4
Exhaust back pressure, kPa	6 to 8	4 max at Step 2 of Stage B
Fuel temperature, °C	40 ± 2	40 ± 2
Fuel lift pump pressure, kPa	Record	Record

^A Stage B length is determined by test time. For a test to be operationally valid, a minimum of 32 000 cycles shall be completed within the 250 h of Stage B.

^B Intended set point, but may vary due to cyclic conditions.

TABLE 4 Stage B, 28-s, Test Cycle

Step	Step Timer, s	Accumulated Time, s	Operation	Engine Throttle Position, %	Speed, r/min	Load, ^A N-m
0	0	0	Idle	0	750 to 850	No load (zero excitation)
1	2.5	2.5	Accelerate to step 2 conditions	100	Ramp up	Ramp up
2	6.0	8.5	Rated speed	100	2600 ^B	800
3	2.0	10.5	Lug ^C to step 4 conditions	0	Ramp down	Ramp down
4	1.0	11.5	Idle	0	750 to 850	No load (zero excitation)
5	2.5	14.0	Accelerate to speed & load within 1.5 s	75 ^D	Peak 1600 to 1750 for min 0.5 s	550 to 750
6	2.0	16.0	Lug ^C to step 7 conditions	0	Ramp down	Ramp down
7	1.0	17.0	Low Idle	0	750 to 850	No load (zero excitation)
8	2.5	19.5	Accelerate to speed & load within 1.5 s	75 ^D	Peak 1600 to 1750 for min 0.5 s	550 to 750
9	2.0	21.5	Lug ^C to step 10 conditions	0	Ramp down	Ramp down
10	1.0	22.5	Idle	0	750 to 850	No load (zero excitation)
11	2.5	25.0	Accelerate to speed & load within 1.5 s	75 ^D	Peak 1600 to 1750 for min 0.5 s	550 to 750
12	2.0	27.0	Lug ^C to step 13 conditions	0	Ramp down	Ramp down
13	1.0	28.0	Idle	0	750 to 850	No load (zero excitation)

^A This is the nominally observed load.

^B Engine speed average (over 6 s) shall be 2600 ± 50 r/min. An initial overshoot between 2650 and 2800 r/min is allowed.

^C Engine speed shall come to idle before reaching a no load condition, i.e., the load forces the speed down.

^D Approximate throttle position to reach specified speed and load.

11. Calculations, Ratings, and Test Validity

11.1 Crosshead-Mass Loss:

11.1.1 Use the procedure in 8.1.5 to determine and report the pre-test and EOT mass of the individual crossheads.

11.1.2 Separate the crossheads into intake and exhaust groups.

11.1.3 Calculate and report the mass loss for each crosshead as pre-test mass minus EOT mass. Calculate and report the average, crosshead-mass loss for both the intake and exhaust groups.

11.1.4 Use Practice E178, two-sided test at a 95 % significance level, to determine if any crosshead-mass loss values are outliers (keeping the intake and exhaust groups separate). Report the outlier-screened, average crosshead-mass loss values for both the intake and exhaust groups. If no outliers are identified, these values will be the same as the values calculated in 11.1.3.

11.1.5 Calculate the overall, outlier-screened, average, crosshead-mass loss as follows:

$$CAWL = (OACWLI + OACWLE)/2 \quad (1)$$

where:

CAWL = outlier-screened, average, crosshead-mass loss, mg,

OACWLI = outlier-screened, average, intake crosshead-mass loss (11.1.4), mg, and

OACWLE = outlier-screened, average, exhaust crosshead-mass loss (11.1.4), mg.

11.1.6 Calculate and report the average, crosshead-mass loss, adjusted to 3.50 mass % soot as follows:

$$ACWL = CAWL - 1.3(TGAAVG - 3.50) \quad (2)$$

where:

ACWL = average, crosshead-mass loss adjusted to 3.50 mass % soot, mg, and

TGAAVG = average of the nine Thermal Gravimetric Analysis (TGA) soot-concentration measurements from 25 h to 350 h (see 11.4 and Table A9.1), mass %.

11.2 Tappet-Mass Loss:

11.2.1 Use the procedure in 8.1.6 to determine and report the pre-test and EOT mass of the individual tappets.

11.2.2 Separate the tappets into intake and exhaust groups.

11.2.3 Calculate and report the mass loss for each tappet as pre-test mass minus EOT mass. Calculate and report the average, tappet-mass loss for both the intake and exhaust groups.

11.2.4 Use Practice E178, two-sided test at a 95 % significance level, to determine if any tappet-mass loss values are outliers (keeping the intake and exhaust groups separate). Report the outlier-screened, average, tappet-mass loss values for both the intake and exhaust groups. If no outliers are identified, these values will be the same as the values calculated in 11.2.3.

11.2.5 Calculate the overall, outlier-screened, average, tappet-mass loss as follows:

$$TWL = (OATWLI + OATWLE)/2 \quad (3)$$

where:

TWL = outlier-screened, average, tappet-mass loss, mg,

OATWLI = outlier-screened, average, intake tappet-mass loss (11.2.4), mg, and

OATWLE = outlier-screened, average, exhaust tappet-mass loss (11.2.4), mg.

11.2.6 Calculate and report the average, tappet-mass loss (soot-adjusted) as follows:

11.2.6.1 For all tests starting on or before January 24, 2007:

$$ATWL = TWL - 76(TGAAVG - 3.50) \quad (4)$$

where:

ATWL = average, tappet-mass loss (soot adjusted), mg,
 TWL = outlier-screened, average, tappet-mass loss, mg, and
 TGA AVG = average of the nine TGA soot measurements from 25 h to 350 h (see 11.4 and Table A9.1), mass %.

11.2.6.2 For all tests starting on or after January 25, 2007:

$$ATWL = TWL - 39(TGA\text{AVG} - 3.48) \quad (5)$$

(1) The value to be used for TGA AVG depends on its magnitude:

- (a) If the average falls within the range 2.92 to 4.04 mass %, use the measured value.
- (b) If the average is less than 2.92 mass %, use 2.92.
- (c) If the average is greater than 4.04, use 4.04.

11.3 Camshaft Wear:

11.3.1 Use the procedure in 8.1.7 to determine the pre-test and EOT measurements of the individual camshaft lobes.

11.3.2 Separate the cam lobes into intake and exhaust groups.

11.3.3 Calculate and report the wear for each cam lobe as pre-test measurement minus EOT measurement. Calculate the average, camshaft wear for both the intake and exhaust groups.

11.3.4 Use Practice E178, two-sided test at a 95 % significance level, to determine if any camshaft-wear values are outliers (keeping the intake and exhaust groups separate). Report the outlier-screened, average, camshaft-wear values for both the intake and exhaust groups. If no outliers are identified, these values will be the same as the values calculated in 11.3.3.

11.3.5 Calculate the overall, outlier-screened, average, camshaft wear as follows:

$$ACSW = (OACSWI + OACSWE)/2 \quad (6)$$

where:

ACSW = outlier-screened, average, camshaft wear, μm ,
 OACSWI = outlier-screened, average, intake camshaft wear (11.3.4), μm , and
 OACSWE = outlier-screened, average, exhaust camshaft wear (11.3.4), μm .

11.4 *Oil Analyses*—Analyze the oil samples for concentration of wear metals, base number (TBN), acid number (TAN), TGA soot value, and viscosity at 100°C according to the schedule and methods shown in Table A9.1 and report.

11.5 *Fuel Analyses*—Report the analyses provided by the fuel supplier. Report the analyses of the final batch if more than one fuel batch was used.

11.5.1 *Additional Analyses*—Perform and report the following analyses on the 120-mL, new, and EOT fuel samples:

11.5.1.1 API gravity at 15.6°C (60°F), Test Method D4052.

11.5.1.2 Total sulfur, ppm (mg/kg), Test Method D5453 (D2622, or D4294 can be substituted).

11.6 *Assessment of 28-s Cycle Validity*—Collect data at an acquisition rate of at least 10 Hz and plot speed (r/min) and load (N·m) versus time. The resulting plot of the cycle will indicate that the engine achieved the conditions set forth in the test procedure.

11.7 *Assessment of Test Validity*—To be operationally valid, tests shall complete no less than 32 000 cycles during Stage B within the 250 h and shall meet the 100-h soot window of 3.25 ± 0.25 mass %.

12. Report

12.1 *Reporting Reference Oil Test Results*—For TMC reference oil tests, use the standardized report form set and data dictionary for reporting test results and for summarizing operational data. Report forms and the data dictionary are available from the TMC.² Fill out the report forms according to the formats shown in the data dictionary. When transmitting data electronically, a Header Data Dictionary shall precede the data dictionary. The latest version of this Header Data Dictionary can be obtained from the TMC.² Report test results in the units and with the significant digits shown in Table A8.2. Round the data in accordance with Practice E29.

12.1.1 During the test, if the engine is shut down or operated out of test limits, record the test hours, time, and date on the appropriate form. In addition, note all prior reference oil tests that were deemed operationally or statistically invalid in the comment section.

12.1.2 When reporting reference oil test results, transmit the test data electronically by utilizing the ASTM Data Communications Committee Test Report Transmission Model (see Section 2, Flat File Transmission Format) which is available from the TMC. Transmit the data within five working days of test completion. Mail a copy of the final test report within 30 days of test completion to the TMC.²

12.2 *Deviations from Test Operational Limits*—Report all deviations from specified test operational limits on the appropriate form.

13. Precision and Bias

13.1 *Precision*—Test precision is established on the basis of operationally valid reference oil test results monitored and updated by the TMC periodically. Contact the TMC² for current industry data. Table 5 summarizes the reference oil precision from operationally valid tests through October 20, 2007.

13.1.1 *Intermediate Precision Conditions*—Conditions where test results are obtained with the same test method using the same test oil, with changing conditions such as operators, measuring equipment, test stands, test engines, and time.

NOTE 6—The Intermediate precision is the appropriate term for the method rather than repeatability which defines more rigorous within-laboratory conditions.

TABLE 5 Test Precision^A

Test Result	Measured Units	
	Intermediate Precision, i.p.	Reproducibility, R
Average Camshaft Wear, μm	16.6	16.9
Average Tappet Mass Loss, mg	39.1	39.9
Average Crosshead Mass Loss, mg	1.25	1.44

^A These statistics were obtained from the TMC.² They are based on results obtained five laboratories on TMC Reference Oils 830-2, 831, and 821 over the period October 2005 through October 20, 2007.

13.1.2 *Intermediate Precision Limit (i.p.)*—The difference between two results obtained under intermediate precision conditions that would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in **Table 5** in only one case in twenty. When only a single test result is available, the Intermediate Precision Limit can be used to calculate a range (test result \pm Intermediate Precision Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.1.3 *Reproducibility Conditions*—Conditions where test results are obtained with the same test method using the same test oil in different laboratories with different operators using different equipment.

13.1.4 *Reproducibility Limit (R)*—The difference between two results obtained under reproducibility conditions that

would, in the long run, in the normal and correct conduct of the test method, exceed the values shown in **Table 5** in only one case in twenty. When only a single test result is available, the Reproducibility Limit can be used to calculate a range (test result \pm Reproducibility Limit) outside of which a second test result would be expected to fall about one time in twenty.

13.2 *Bias*—No estimate of bias for this procedure is possible, as the behavior of an oil is determined only under the specific conditions of the test and no absolute standards exist.

14. Keywords

14.1 diesel engine oil; heavy-duty engine oil; ISB medium-duty diesel engine; lubricants; valve-train wear

ANNEXES

(Mandatory Information)

A1. SAFETY PRECAUTIONS

A1.1 The operating of engine tests can expose personnel and facilities to safety hazards. Personnel trained and experienced with engine testing should perform the design, installation, and operation of test stands.

A1.2 Install guards (shields) around all external moving, hot, or cold components. Design the guard to contain the energy level of a rotating component should the component break free. Fuel, oil, coolant, and electrical wiring should be properly routed, guarded, grounded and kept in good order.

A1.3 Keep the test stand free of oil and fuel spills and tripping hazards. Do not permit containers of oil or fuel, or both, to accumulate in the testing area. Fire fighting equipment should be immediately accessible. Observe normal precautions whenever using flammable solvents for cleaning purposes.

A1.4 Safety masks, glasses, or hearing protection, or a

combination thereof, should be worn by personnel working on the test stand. No loose or flowing clothing, including long hair or other accessory to dress, should be worn near rotating equipment. Caution personnel against working alongside the engine and driveline while the engine is running.

A1.5 Interlocks should automatically shutdown the engine when an anomaly in any of the following occur: engine or dynamometer coolant temperature, engine oil pressure, dynamometer field current, engine speed, exhaust temperature, excessive vibration, or when the fire protection system is activated. The interlock should include a method to cut off the fuel supply to the engine at the injector pump (including the return line). A remote fuel cut off station (external to the test stand) is recommended.

A1.6 Employ other safety precautions as required by regulations.

A2. INTAKE AIR AFTERCOOLER

A2.1 Obtain the Modine aftercooler (part number 1A012865) from one of the following sources:

Central Parts Distributor (CPD)^{5,6}
 Kraft Power Corporation, 1229 Nessley Road, Lancaster, PA 17601
 Local Mack Trucks Inc. (www.macktrucks.com) dealer

NOTE A2.1—When ordering via a local Mack Trucks Inc. dealer, use part number 5424 03 928 031. This is a non-stocked part in the Mack Parts Distribution System and will appear as an invalid part number. Instruct the dealer to expedite via a Ship Direct purchase order. The aftercooler will then be shipped from Modine directly, bypassing the normal Mack Parts Distribution System.

A3. THE CUMMINS ISB ENGINE BUILD PARTS KIT

A3.1 Engine Build Parts Kit is available from the supplier listed in A2.1. Components are shown in Table A3.1.

TABLE A3.1 ISB Engine Build Parts Kit

Description	Part Number	Quantity
Camshaft	3954099	1
Tappet	3947759	12
Crosshead	3943626	12
Push Rod	3941253	12
Rocker Shaft	3935892	12
Rocker Lever, Intake (short)	3937219	6
Rocker Lever, Exhaust (long)	3937220	6
Rocker Support	3941559	6
Oil Pan Seal	3959797	1
Rear Seal	4890833	1
Test Oil Filter	3937736	1
Rocker Cover Seal	3954324	1

A4. SENSOR LOCATIONS AND SPECIAL HARDWARE

A4.1 The following lists the various engine modifications and the relevant figures that detail the changes and sensor locations.

- A4.1.1 *Oil Heat Exchanger Bypass Plate*—See Fig. A4.1.
- A4.1.2 *Remote Filter Head Bypass*—See Fig. A4.2.
- A4.1.3 *Remote Oil Heat Exchanger*—See Fig. A4.3.
- A4.1.4 *Oil Pan Modifications*—See Fig. A4.4.
- A4.1.5 *Blowby Elbow to Blowby Barrel*—See Fig. A4.5.
- A4.1.6 *Intake Air System*—See Figs. A4.6-A4.8.
- A4.1.7 *Remote Oil Filter*—See Fig. A4.9.

- A4.1.8 *Aftercooler Installation*—See Fig. A4.10.
- A4.1.9 *Exhaust System*—See Fig. A4.11.
- A4.1.10 *Oil-Gallery Temperature and Pressure*—See Fig. A4.12.
- A4.1.11 *Crankcase-Pressure Measurement Point*—See Fig. A4.12.
- A4.1.12 *Fuel-Temperature Measurement*—See Fig. A4.13.
- A4.1.13 *Fuel-Pressure Measurement*—See Fig. A4.14.
- A4.1.14 *Coolant-Temperature Outlet and Inlet Measurement*—See Fig. A4.15.



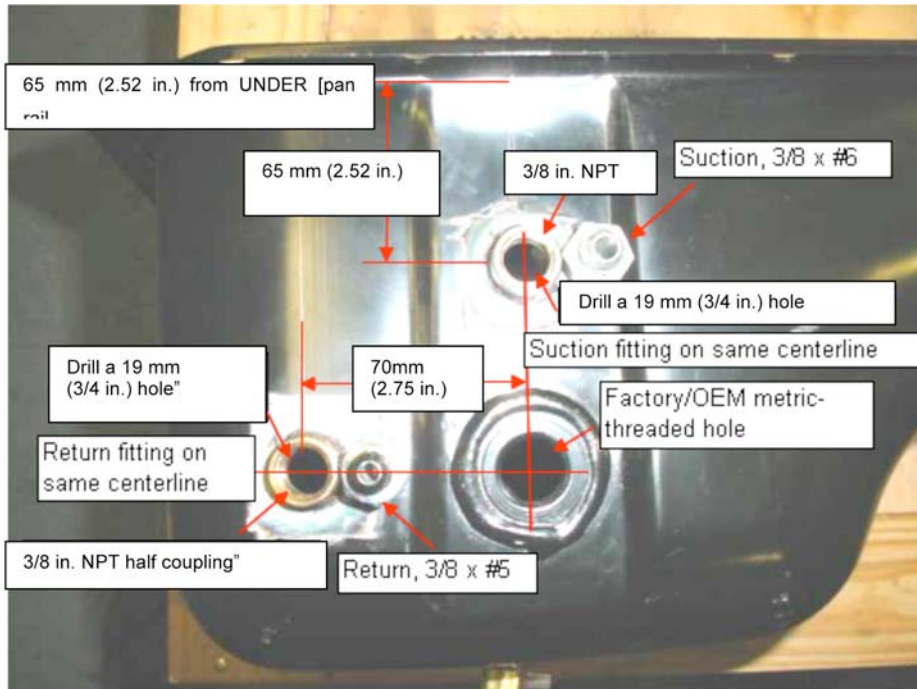
FIG. A4.1 Oil Heat Exchanger Bypass Plate



FIG. A4.2 Remote Filter Head Bypass



FIG. A4.3 Remote Oil Heat Exchanger



(a) External Modifications



(b) Internal Modifications

FIG. A4.4 Oil Pan Modifications



FIG. A4.5 Location of the Elbow for Venting the Blowby Gas

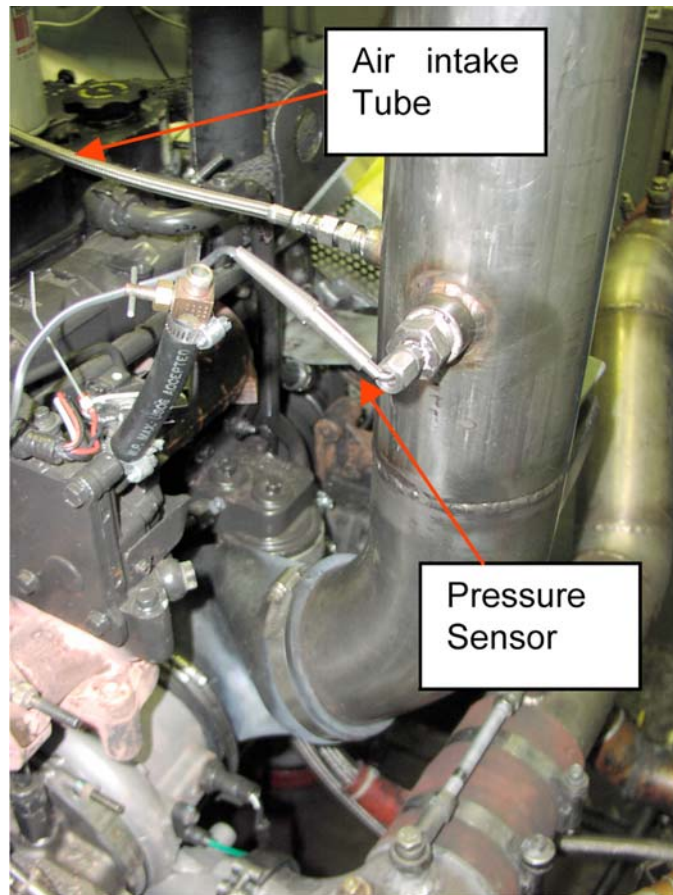


FIG. A4.6 Configuration of the Intake Air System

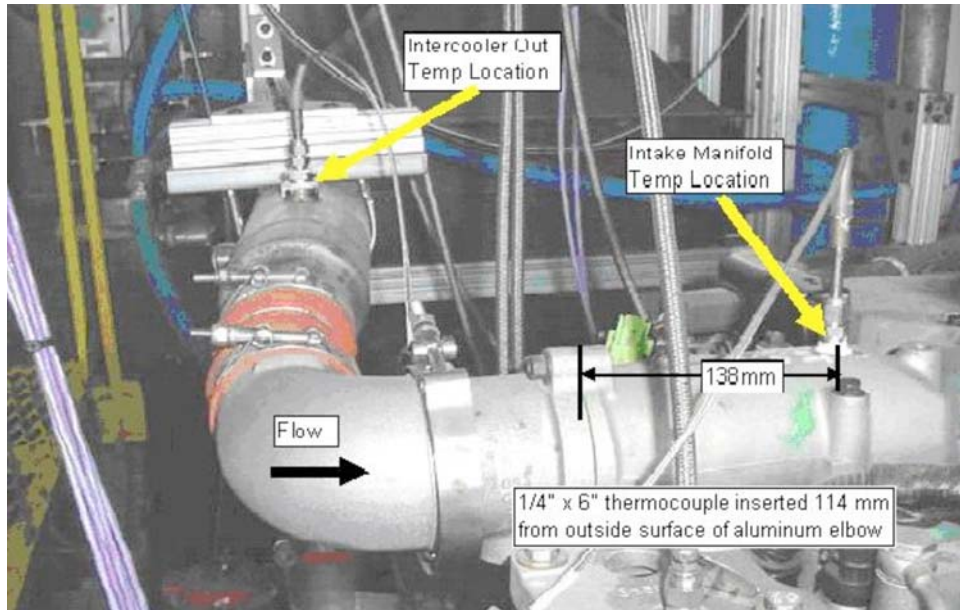


FIG. A4.7 Location of Sensor for Intake Manifold Temperature Measurement



FIG. A4.8 Location of Sensor for Intake Manifold Pressure Measurement

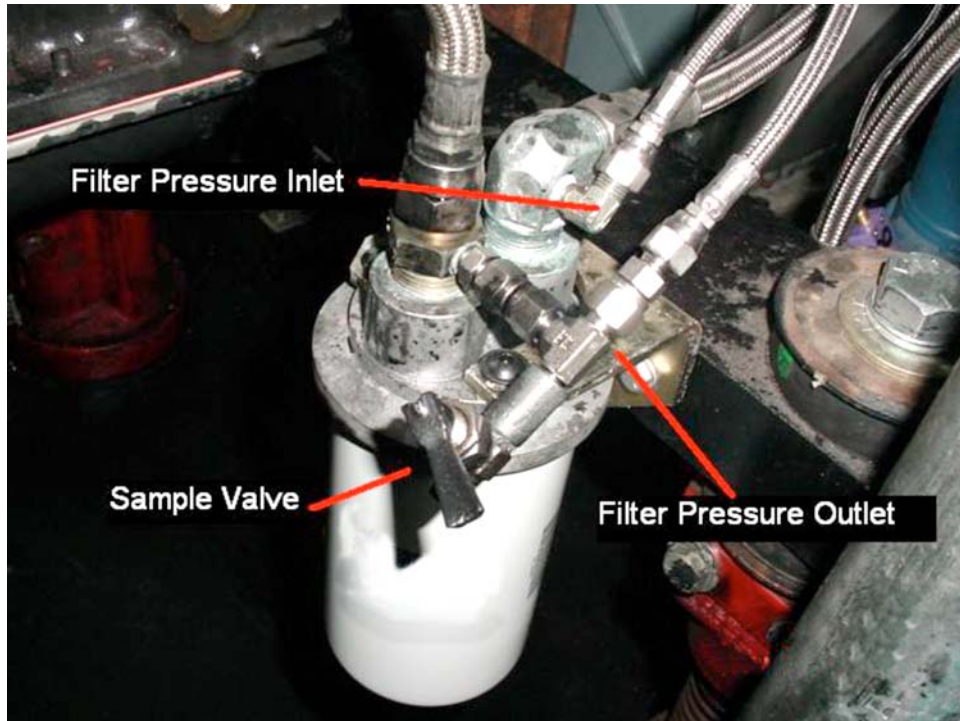


FIG. A4.9 Remote Oil Filter Showing Location of Sensors for Inlet and Outlet Pressure and the Recommended Location of the Oil Sample Valve

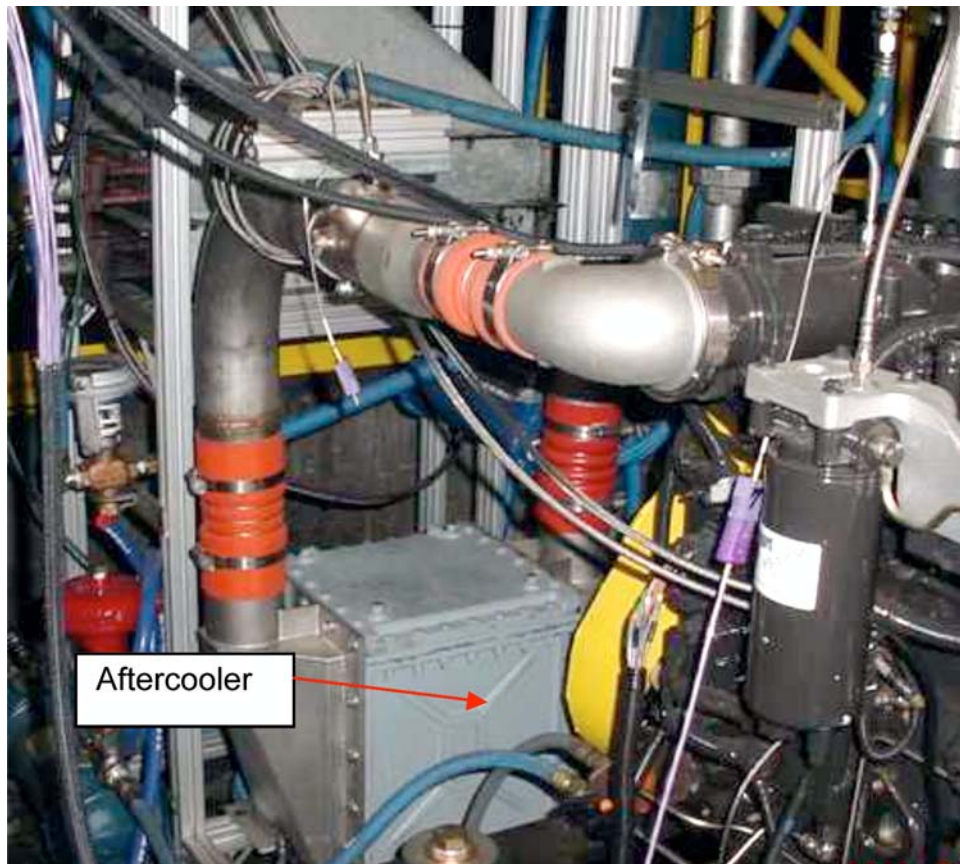


FIG. A4.10 Aftercooler Installation

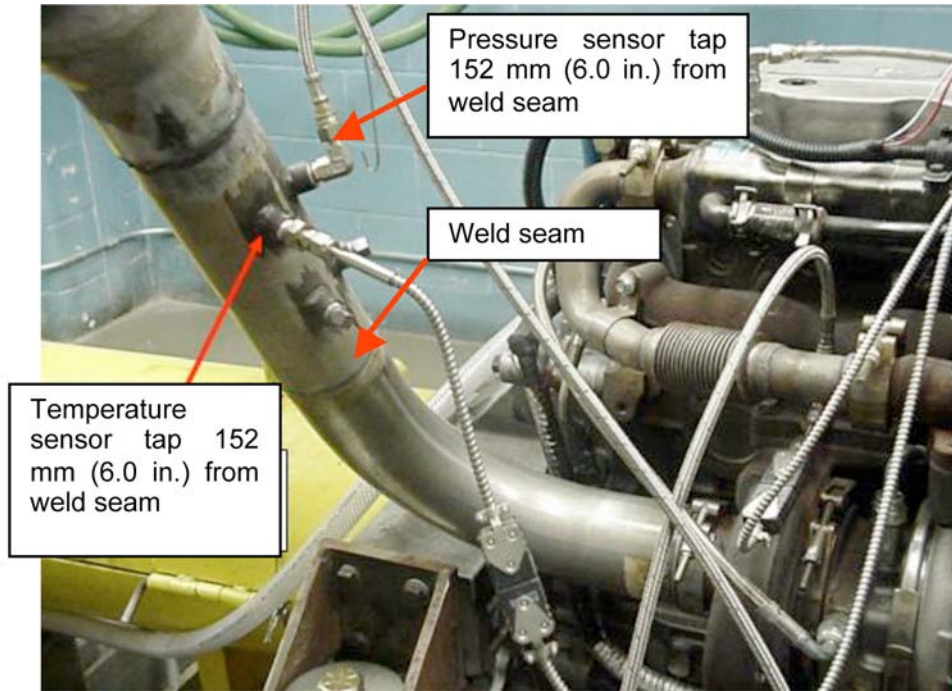


FIG. A4.11 Exhaust System Showing Location of Taps for Temperature and Pressure Sensors

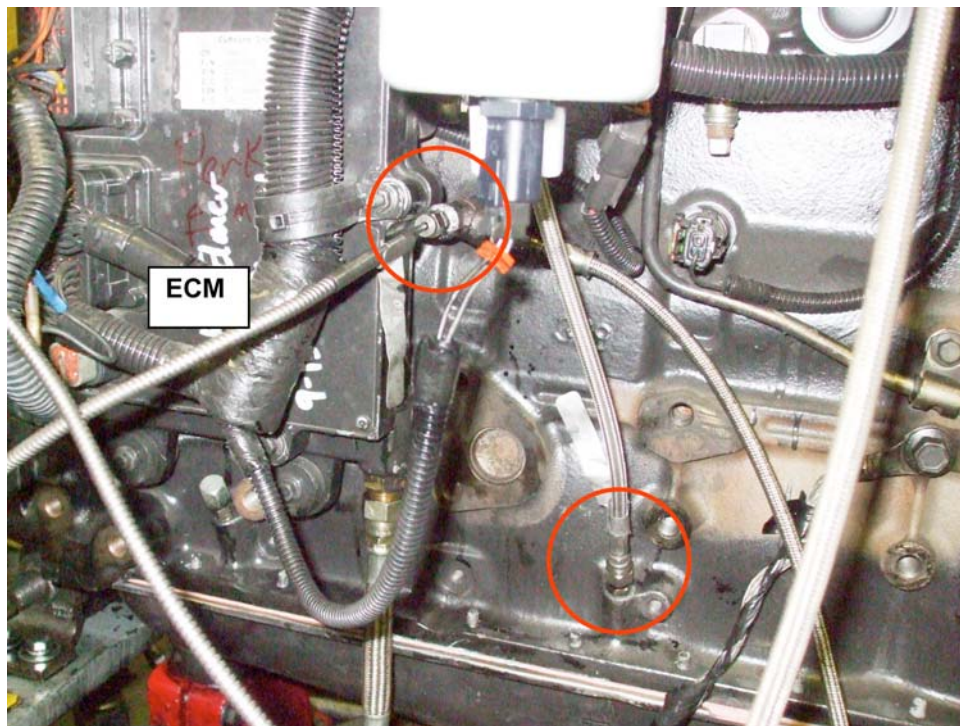


FIG. A4.12 Location of Sensors for Oil Gallery Temperature and Pressure and Crankcase-Pressure Measurement

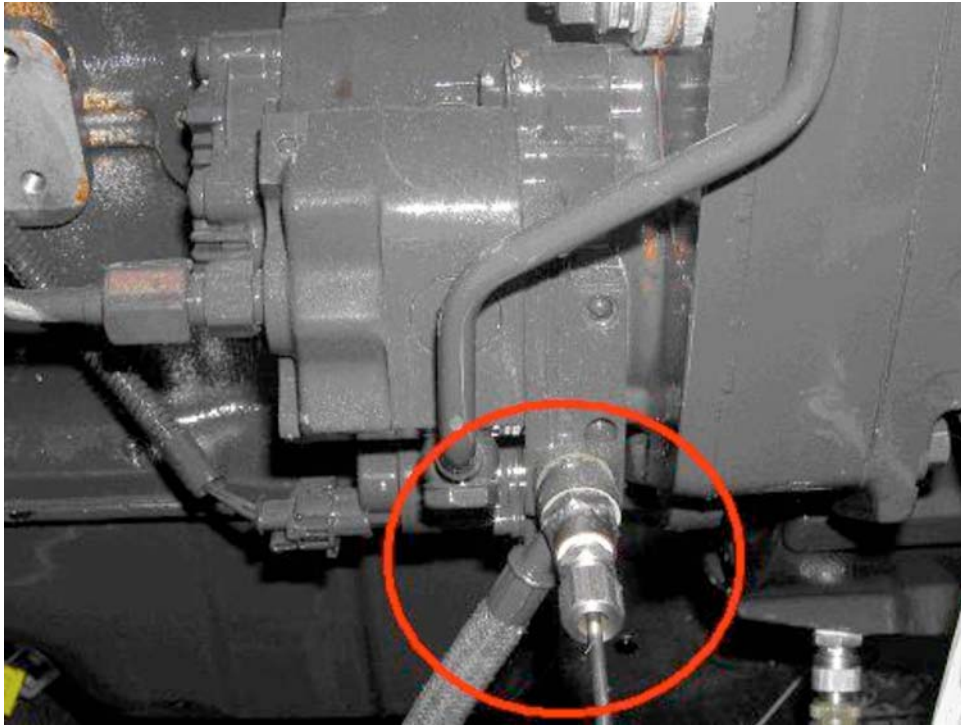


FIG. A4.13 Location of Sensor for Fuel-in Temperature Measurement

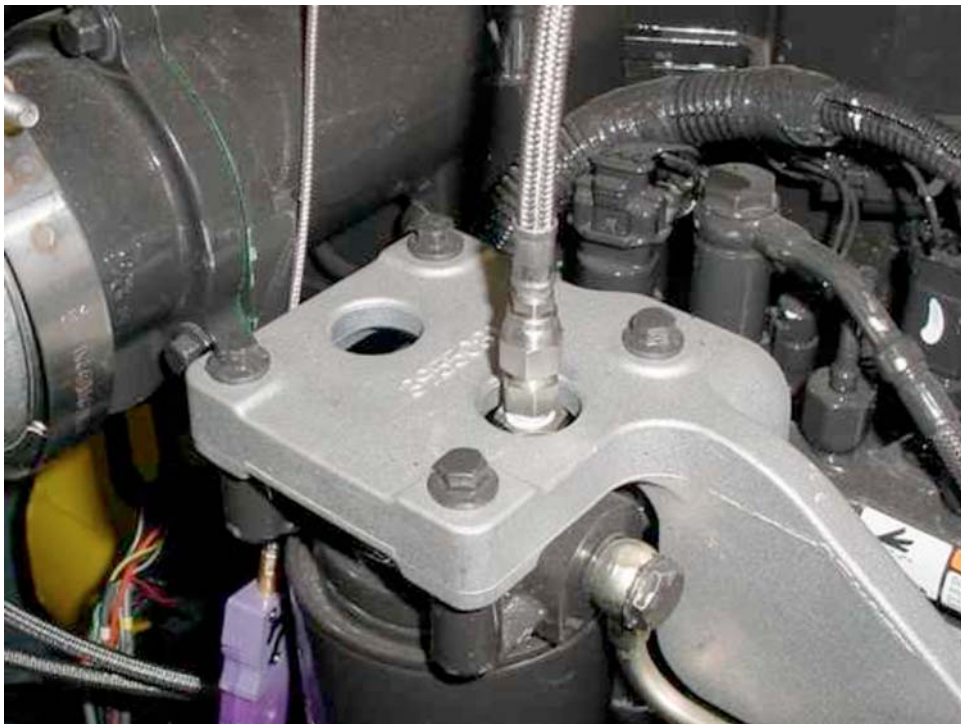
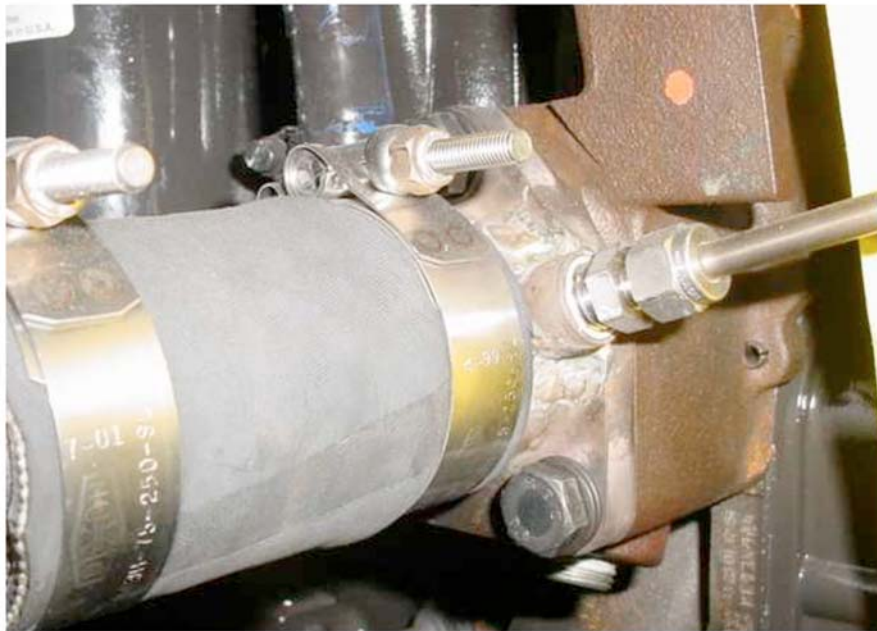


FIG. A4.14 Location of Sensor for Fuel-Pressure Measurement



(a) Coolant out

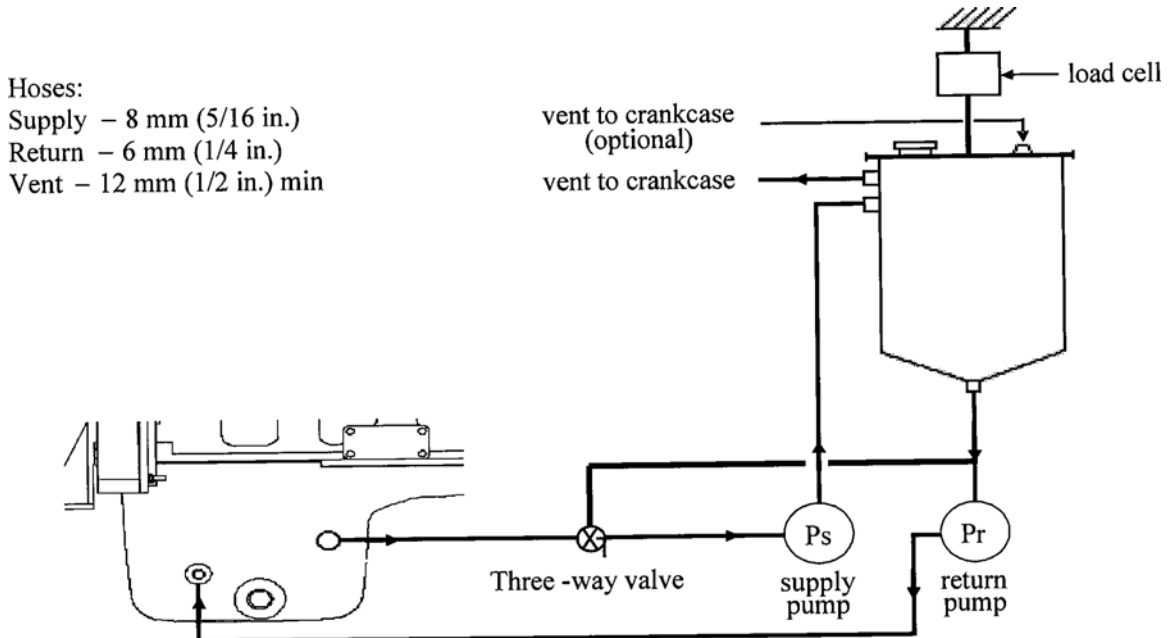


(b) Coolant in

FIG. A4.15 Location of Sensors for Coolant-Temperature Measurement

A5. EXTERNAL OIL SYSTEM

A5.1 See Fig. A5.1.



A6. FUEL SPECIFICATION

A6.1 See Table A6.1.

TABLE A6.1 Fuel Specification

Property	Specification	Test Method
Additives	Lubricity additive only	
Distillation Range, °C, 90 %	293 to 332	ASTM D86
Specific Gravity	0.840 to 0.855	ASTM D4052
API Gravity	34 to 37	ASTM D4052
Corrosion, 3 h at 50 °C	1 max	ASTM D130
Sulfur, ppm (mg/kg)	7 to 15	ASTM D5453
Flash Point, °C	54 min	ASTM D93
Pour Point, °C	-18 max	ASTM D97
Cloud Point, °C	Report	ASTM D2500
Viscosity at 40 °C, m ² /s	2.0 to 2.6	ASTM D445
Ash, mass %	0.005 max	ASTM D482
Carbon Residue on 10 % Bottoms	0.35 max	ASTM D524
Net Heat of Combustion, MJ/kg (Btu/lb)	Report	ASTM D3338
Water and Sediment, volume %	0.05 max	ASTM D2709
Acid Number	0.05 max	ASTM D664
Strong Acid Number	0 max	ASTM D664
Cetane Index	Report	ASTM D976
Cetane Number	43 to 47	ASTM D613
Accelerated Stability, mg/100 mL	1.5 max	ASTM D2274
Composition		
Aromatics, mass %	26 to 31.5	ASTM D5186
Olefins, volume %	Report	ASTM D1319
Saturates, volume %	Report	ASTM D1319
SLBOCLE, ^A g	3100 min ^B	ASTM D6078 ^C

^A Scuffing Load Ball-on-Cylinder Lubricity Evaluator.

^B May be altered to be consistent with CARB or ASTM diesel fuel specifications.

^C Procedure A.

A7. CUMMINS SERVICE PUBLICATIONS

A7.1 General preparation techniques, as well as, engine specifications, component specifications and torque values for Cummins ISB engines are detailed in the Cummins publication entitled *Troubleshooting and Repair Manual ISB^e and ISB (Common Rail Fuel System) Series Engines*, Bulletin Number 4021271, June 30, 2004. The manual is available from Cummins Parts Distributors.

A7.2 The following Cummins publication also contains information relevant to the ISB engine: *Troubleshooting and Repair Manual ISB, ISB^e, QSB 4.5, QSB 5.9, QSB 6.7, ISC, QSC 8.3, ISL and QSL 9 Engines, CM 850 Electronic Control System Engines*, Bulletin Number 4021416.

A8. SPECIFIED UNITS AND FORMATS

A8.1 Specified Units:

A8.1.1 The parameters in this test method are specified in SI units except for pipe fittings, tubing, and tubing fittings. These are available worldwide and are not interchangeable with SI-sized equivalents because of differences in thread dimensions. As a consequence, no SI conversion is stated. The ports are standard straight thread and are not interchangeable with SI-sized equivalents.

A8.1.2 *Test Report*—Record operational parameters according to **Table A8.1**. Report test results in the units and with the significant digits shown in **Table A8.2**. Round test results in compliance with Practice **E29**.

A8.1.3 *Measurements and Conversions*—With the exceptions noted in **A8.1.1**, all parameters have been specified in SI units. The intent of this test method is to measure all parameters directly in SI units. If parameters are measured in inch-pound units, then the laboratory shall be able to demonstrate to the TMC that the measurements are within the tolerance after conversion to SI units.

NOTE A8.1—**Caution:** Significant error can occur due to rounding or

TABLE A8.1 Minimum Resolution of Recorded Measurements

Parameter	Record Data to Nearest
Speed	1 r/min
Power	1 kW
Load	1 N·m
Fuel Flow	0.1 kg/h
Coolant In Temperature	0.1°C
Coolant Out Temperature	0.1°C
Fuel In Temperature	0.1°C
Oil Gallery Temperature	0.1°C
Intake Air Temperature	0.1°C
Exhaust (Tailpipe) Temperature	1°C
Intake Manifold Pressure	0.1 kPa
Crankcase Pressure	0.01 kPa
Exhaust Pressure	0.1 kPa

TABLE A8.2 Significant Digits for Test Results

Parameter	Round Off to Nearest
Mass Loss	0.1 mg
Sludge	0.1 merit
Filter Plugging	1 kPa

tolerance stacking, or both, when converting from inch-pound units to SI units.

A8.2 *Specification Format*—Specifications are listed in three formats: (1) target, (2) target and range, and (3) range with no target.

A8.2.1 *Target*—A target specification has no tolerance; as a consequence, the only acceptable result is the target. A representative specification format is xx.xx (target). For example, the oil pan oil charge is listed as 14.5 kg.

A8.2.1.1 A parameter with a target shall not be intentionally calibrated or controlled at a level other than the target.

A8.2.2 *Target and Range*—A target and a range specification implies the correct value is the target and the range is intended as a guide for maximum acceptable variation about the mean. A representative specification format is xx.xx ± x.xx (target ± range). For example, the engine speed is 1600 ± 10 r/min.

NOTE A8.2—The mean of a random sample should be equivalent to the target. Operation within the range does not imply that parameter will not bias the final test results.

A8.2.3 *Range with No Target*—A range with no target specification is used when (1) the parameter is not critical and control within the range is sufficient, or (2) the measurement technique is not precise, or both. A representative specification format is xx.xx to xx.xx (range low to range high). For example, the coolant system pressure is 99 to 107 kPa.

A9. OIL ANALYSES

A9.1 See [Table A9.1](#).

TABLE A9.1 Schedule and Methods for Oil Analyses as Required in 11.4

Sample Schedule Hour	Parameter					TGA Soot Value, ^E mass %
	Metals Concentration, ^A mg/kg	Acid Number ^B	Base Number ^C	Kinematic Viscosity @100°C, ^D m ² /s		
0	X	X	X	X	X	X
25	X	X	X	X	X	X
50	X	X	X	X	X	X
75	X	X	X	X	X	X
100	X	X	X	X	X	X
150	X	X	X	X	X	X
200	X	X	X	X	X	X
250	X	X	X	X	X	X
300	X	X	X	X	X	X
350	X	X	X	X	X	X

^A Determine copper, iron, lead, chromium, and aluminum concentration by Test Method [D5185](#).

^B Determine by Test Method [D664](#).

^C Determine by Test Method [D4739](#).

^D Determine by either Test Method [D5967](#), Annex A3 or Test Method [D445](#).

^E Determine by the Thermal Gravimetric Analysis (TGA) procedure described in Annex A4 of Test Method [D5967](#).

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